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PHENOMENOLOGICAL STUDY OF POSTGRADUATE RESEARCHERS' EXPERIENCES OF NANOSCIENCE AND NANOTECHNOLOGY RESEARCH

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ABSTARCT

Over the past few decades, scientific disciplines have changed significantly with the introduction of new and complex aspects of interdisciplinary research, particularly in the area of nanoscience and nanotechnology (N&N). The current attempts to develop science education programmes in N&N area to adopt these complex changes however are mainly focussed towards the core scientific knowledge, and, not much attention has been paid to identify the attributes knowledge, skills and competences necessary to successfully undertake N&N research. Identification of these attributes is important so that the core scientific knowledge can be embedded in the curricula more effectively. Also, to work successfully in this complex research area, whether one should have studied under specialised undergraduate or postgraduate N&N programme or basic science discipline/s is not yet clear. This qualitative study will examine the postgraduate researchers' experiences of researching in N&N area in order to get a better insight and understanding of what nanoscience and nanotechnology research is. This is in turn will inform curriculum development at undergraduate and postgraduate levels, and it will also address the issues of whether we should have specialised undergraduate N&N programmes or this research area requires different distinct science and engineering disciplines coming together.

Keywords interdisciplinary skills, science curricula, phenomenological interviewing

INTRODUCTION

The area of Nanoscience and nanotechnology (N&N), which encapsulates several scientific disciplines such as physics, chemistry, biology, bio-technology, molecular biology and engineering, is considered to be one of the most important scientific disciplines of the 21st century [1]. The essence of N&N research is to manipulate, control and create the atomic and molecular level assembly which are of the size of nanometres (10^{-9} meters) and study their properties and interactions for specific purpose [2]. Therefore the researchers working in N&N area can experience the novel phenomenon and/or processes at nanoscale while researching in any of the above mentioned discipline/s.

N&N has impacted many important industries, such as aerospace, automotive, biotechnology, ceramics, chemicals, electronics, metals, materials, renewable/sustainable energy, textiles and telecommunications [3]. The potential of N&N research to impact on these industries and thereby on the economy has attracted government and private sector funding. As a result, significant increases in the financial investments in this area have been observed in recent years [3]. Researchers are expanding their research into, or incorporating elements of, N&N as it is a promising research area with guaranteed funding.

Although funding agencies are greatly funding in N&N research area, they have also raised concerns about the shortages in the workforce in this area [4]. According to NSF (National Science Foundation in the United States more than 2 million jobs and 6 million supporting positions will be generated in N&N area by 2015 [5]. Although every new field initially experiences shortages in workforce, and it is not a new phenomenon, the accelerated growth of N&N and its potential impact on the industrial sector makes it a concern and timely challenge [4]. The nature of N&N research is complex and with the inclusion of several disciplines under one research theme [6], it makes curriculum development in this area challenging. Roco [1] argues that 'the education and training of a new generation of skilled workers in the multidisciplinary perspectives' is a key challenge for educators working on curriculum design in N&N. It has also been reported in qualitative research reports that the industries largely depend on the educational institutes for the development of their workforce and hold a strong belief that the educational institutes have and will further reform science curriculum and training programs where necessary to develop a skilled workforce for N&N [7-8]. Although much has been written about the skill needs in N&N area and the necessity of workforce development to date, the available literature provides very little insight with respect to the actual skills needed to be a nanoscience researcher [9-11]. Although many national and international nanotechnology research programmes recommend the development and implementation of educational programmes in N&N, the level at which these programmes should be introduced still remains under debate [12]. Tinker [13] emphasises reconstructing the K-12 science curriculum in the United States to take a more interdisciplinary approach while Zeng *et al*. [14], Samet [15] and Horn [10] have instead discussed possible reforms for undergraduate programmes in science and engineering. Prof. Besenbacher, Director of iNANO (Interdisciplinary Nanoscience Centre, Denmark), in his talk [16] in 2003**,** suggested that the specialised knowledge for cross-disciplinary nanotechnology research may only be needed at a late stage in a researcher's career and the undergraduate curricula should therefore focus mainly on core knowledge needed for a foundation in all specialisations.

Furthermore, although much of the previously published literature has discussed the scientific knowledge, i.e., content focussed information or core knowledge, within N&N curricula, the knowledge, skills and competences the students are expected to develop, enhance and practise through these educational programmes are less researched and discussed.

N&N research area may not progress as fast as it can if, the knowledge, skills and competences necessary to work in this complex area are not developed in the researchers, working in this area presently or in near future. Therefore, it is imperative for the education community to identify in time the necessary attributes and then if necessary, reform science curriculum and training programs in a more targeted manner. Although very little of the research dealing with nanoscience educational reforms pay any attention to researchers' experiences, the authors believe that the researchers are active members experiencing the area in person and their experiences will inform curriculum reforms significantly. Levin [17] have emphasised the meaningful role of undergraduate students in defining and shaping education reforms and discussed some ways in which it can occur.

In Ireland, no specific training programme has been developed for the postgraduate researchers who are engaged in research in N&N area [18] except the INSPIRE (Integrated nanoscience platform for Ireland) postgraduate training programme which is still under development [19]. This study will examine the researchers' experiences in order to get a better insight and understanding of what nanoscience and nanotechnology research is and in turn will inform curriculum development at undergraduate and postgraduate levels about necessary reforms.

POSTGRADUATE RESEARCHER

It takes a postgraduate researcher approximately three to five years to complete their PhD programme in a typical science and engineering research framework. During this period, the researcher is expected to make a significant contribution to the field of research through independent investigations, demonstrate his/her research skills and publish papers and/or a thesis to disseminate his/her research work among the scientific community. For a postgraduate researcher, the research is a journey of generating knowledge in that area and postgraduate researchers working in the area of N&N, which is a comparatively new and complex area, are also following the same research tradition.

THEORETICAL FRAMEWORK AND RESEARCH DESIGN

Human experiences are descriptive in nature and can be illustrated qualitatively [20-24]. As this research focus on postgraduate researchers' experiences and their descriptions, qualitative approaches best suit the purpose. While following qualitative approach, we have subscribed to Creswell's framework of qualitative research consisting of three fundamental elements 1) knowledge claims, 2) strategies of enquires and 3) methods of data collection and analysis [20]. We have applied phenomenology as methodology or strategy of enquiry; and open ended interviews as a specific method of data collection for this research.

Dartigues [23] has argued that the examination of experiences or life world can provide an insight of the knowledge or underlying reasons of the actions. In this qualitative research, examining the life-world or experiences was the most crucial part of the research process and is not possible without gathering exact life world experiences from the participants. The life worlds for the postgraduate researchers include their research laboratories, meetings with supervisors, group meetings and conferences where research takes shape though experiential processes, therefore the interviewer should try to collect and describe the participants' (postgraduate researchers') experiences of these 'life worlds' as fully as possible.

Phenomenology always considers the acts of 'describing' and 'interpreting' human experience or life world as valuable [23]. Although these acts lead to two different strands in phenomenology, they both essentially focus on understanding how the individual assign meaning to their experiences. We believe that phenomenology with its grounding and focus on descriptions and interpretation [24] would be appropriate research methodology for my research of examining the postgraduate researchers' experiences. Phenomenological methodology offers some techniques or methods to collect and examine the data such as interviews and focus groups [25-32]. Bailey [33] has described briefly how the informal open ended interview stand as a conscious attempt to collect the rich life experiences. We have also adopted the open ended interviews in this research to obtain fuller and rich descriptions of postgraduate researchers' experiences. While examining the life experiences the researcher should bracket any presuppositions, prejudices or the understanding of the experience that exists already [28] and should focus on the individual and their interaction with the surroundings. In our research, the bracketing entailed setting aside our knowledge of N&N research and ways in which we think the researcher perceives the world of N&N research and perform inquiry. Interpretive paradigms further enable us to examine the researchers' lived experiences and draw different structures of the meaning of the experiences [29].

We believe that, examination the life experiences of postgraduate researchers can provide an insight of what N&N research is using phenomenological research framework. Postgraduate researchers' life experiences can extrapolate a universal form, as they come from different institutions, work or research environment and scientific disciplines and therefore may experience researching in N&N area in different settings. Although the phenomenological study does not provide the entireness of the experiences due to the limited number of participants but it definitely provides a broader, a fuller and more in depth understanding of N&N research and how the researchers carry it out. Interpretation of their experiences further enables the understanding of the knowledge, skills and competences necessary to work in this area allowing us to reflect on the existing science curricula.

PARTICIPANTS' SELECTION, PHENOMENOLOGICAL INTERVIEWS AND ANALYSIS METHOD

The study was conducted using semi-structured interviews with postgraduate students. There are approximately 300 researchers currently pursuing PhDs in N&N related research areas from different institutes and universities across Ireland [34] and about 40 postgraduates (13% of the entire population of interest) will be interviewed for this study. However this paper is a preliminary study undertaken to inform the process and research design and considers six pilot interviews as an illustrative data set. The data collection began with obtaining participants' information through internet search of university websites and N&N conference abstract books and proceedings published during March 2010 to the latest. We concentrated on six postgraduate researchers based on the purpose of their research. The data set represented a wide variation in terms of the researchers' undergraduate disciplines, research experience and area of research.

The interviews were conducted at the participants' workplace and each lasted for about an hour. During the interviews, the participants were assured about the confidentiality of the data so as to

encourage their involvement in the interview process. In phenomenological interviewing, the interview questions play a significant role in encouraging the participants to delve deeper into their experiences and describe them as fully as they can. The interview questions that were put to participants were open ended and indirect which would probe their experiences about researching in N&N area. Also the interview questions were reduced to a very small number (up to 5) which would provide the participant plenty of time to elaborate their experiences.
The open ended interview questions are designed to allow the data to emerge [35] but there is a danger of collecting long descriptions of mechanical actions and even opinions from the participants instead of their experiences of a particular phenomenon. Although one can certainly avoid the descriptions of actions completely using open ended questions; I endeavoured to use these descriptions to get closer to the experience and using probing questions encouraged them to describe their experiences fuller and deeper. I also tried to maintain 'person centred approach' during the interviews by asking probing questions such as 'what did you do then?' which helped contain the conversation to that of the participant's actions and experiences and encouraged them to describe the experiences as it was experienced by themselves and thereby minimising their opinions.
The interviews were audio recorded with the permission of the participants and transcribed later. The transcripts were taken back to the participants if any clarification was required.
The interview analysis included repetitive reading of the transcripts to get a general feel of the interview. Then we identified the sentences or sections that pertained directly to the experiences of doing nanoscience research. From these sections we developed themes in each transcript which can be supported by quotations or dialogues within the transcripts [36]. We decided to use these themes as headings of sections in phenomenological drafts describing the individual participant's experiences of N&N research within his/her educational, research and social environment or setting. While in this paper, we simply use the themes to gather similar experiences if any. Also we used these themes to compare if different subgroups of the data set (formed according to graduation disciplines or research area) have any similar experiences.

RESEARCH DATA ANALYSIS

It must be kept in mind that the data analysis is preliminary and carried out with an intention of identifying the success of the interview questions to gather researchers' experiences. The findings are drawn from pilot interviews and subjected to change with the actual data set. The themes which emerged from the transcripts were *'dominance of the instrumentation in N&N research'*, *'research collaborations and postgraduate researcher's participation' 'research policies and researchers' impression', 'dynamics in nanoscience research and researchers' attitude' and 'complexities in explaining N&N research'.*

In N&N research, the researchers use the instruments which allow them to characterise the nanoscale objects in terms of size and scale or visualise the nanoscale assembly such as deposition layers, bio/cellular interactions with nanoparticles and devices in the process of development. The interaction of researchers with colleagues or collaborative researchers is mainly about the usage of the equipments or instruments, so the instruments are the common points where researchers who may work in different disciplines meet or share the information. Even within the research cluster, the facility of using the scientific instruments amongst collaborators is supported very strongly. Darby and Zuker (2003) [37] has already pointed out the importance of instrumentation, more specifically the nano-scale instrumentation as an important area that provides a common platform for the various N&N fields. In the researcher's frame of reference, since they are the one who actually uses these instruments for data generation (which can be used by themselves and/or shared within other collaborators) it is necessary to have good discussion about what information obtained using the instrumentation, other collaborative researchers are interested in, particularly when more than one discipline are involved in certain project. It is evident from experiences shared by two participants.

> *In our case…. the work wasn't of sufficient standard. That is true in lot of cases and even in XXXX case also. We have sent samples to a group…I won't mention who for YYY measurement and they have not got into the bottom of it...bottom of the problems…there were too many people involved at upper stage...and postgrads…nobody cares what it is for.. a postdoc sitting there, sends an email…. we have a new collaboration and sends the sample to do this…..they do the experiment and send it back…when we are looking at the data back here… non of them make sense….as nobody was knowing or understood what we were interested in….it is shear wastage of time!! (PhD researcher C)*

This girl PPPP, I was in touch with her through email. …She provided the MMMM for my project. She also gave me the information about the SSSS of the molecules, like the solvent she used while characterizing the molecules. …But you know what, they don't know what we are using MMMM for…..But I am pretty sure.. that she didn't understood what it was for anyways!! In this collaboration, we are not particularly totally dependent on each other or independent, but the outcome of our work or their work won't be completely go wrong, if something goes wrong in any of the side….. ….(PhD researcher D)

The postgraduate researchers consider themselves at the bottom of the chain of a research cluster and are more often ordered to exchange the experimental results or products within collaboration, without having much scope for exchange of the knowledge or information of, what the particular product /data is being used for? From a postgraduate researcher's perspective, they feel it is important to involve them in every step of knowledge exchange in a collaborative project, which could avoid delays, accelerate their research work in a right direction and could bring about healthy research collaborations.

While building up the dialogue between the researchers, they felt that, it was also important that they understand how their information/data can be used in other disciplines. Every scientific discipline has its own set way of thinking and practises [38] and researchers' activities are guided by these practises [38]. Developing a trust on the thinking and practises of other different disciplines is possible when these intertwine at certain stages in the research journey, which is possible predominantly at the stage of instrument usage as stated earlier. The 'explanation of use of data from N&N related instruments' thus can be referred to as 'Center for knowledge transfer' with reference to which researchers can discuss their work. To achieve this, the researchers expressed the need of common vocabulary, with which the concepts can be explained and ideas can be shared across the disciplines at ease. The postgraduate researchers thus can be aware of the potential of other disciplines and make a request for correct information from co-researchers. A stronger research networking is also possible through this common vocabulary. Nanotechnology, being a broad research area, brings together researchers of various scientific disciplines (in the laboratory or at conferences). A common vocabulary can certainly achieve more interactive and constructive discussions and can assist in problem solving. Postgraduate researcher (E) shared his experience at a conference during poster presentation.

Even sometimes… here people are like, Oh that is ecotoxicology.. …that is bit different… I don't know anything about that… But then I just try to explain them still that we are measuring how toxic these MMMM are..basically I just give the idea of what are these tests are and why I am doing it…. I know what are their limitations due to their backgrounds, so …. I kind of describe them using a general terminology which everybody understands, no matter which background they have…and then they are interested in testing it for their QQQQ (PhD researcher E)

The 'commercialisation' of N&N research is identified as one of the main interests of the stake holders [39] and as a consequence the research policies are structured to contribute to it by the research cluster approach. A postgraduate researcher, although an integral part of the research cluster, sometimes finds it difficult or struggles to pursue their research interest and can feel under pressure. From their perspectives, the 'goal posts tend to shift' due to the commercialisation activities and this affects their personal interest in their research.

I was there for a day in MMMM conference but it was total waste!! It was nothing to do with research. It was more for commercialization and I think they were trying to drag the students for….(PhD researcher A)

It is terrible when you are doing something and the other people who are powerful would cut your funding…and then the other people in the research cluster quickly gather a plan which is pretty poor …it is very annoying subject….. we had lot's of ideas but…there were a strong influential personalities in the research cluster that wanted to direct it towards a particular application for DDDD …. which has been done a lot and to be honest with you, personally, I have no interest in it unfortunately…honestly, I will ignore it….it will affect the research cluster but will not effect me because initially a vast amount of time was wasted as it always jumped from topic to topic….it was purely bureaucratic nonsense… I mean people fighting…it happen…it is the person in the bottom of the chain who always suffers!! (PhD researcher A)

Postgraduate researchers can be made aware of the big picture of current trends of research policy developments and perspectives; commercial enterprise perspectives; social aspects of research and significance of researchers' contribution in overall research development, probably through training and curricula, which could minimise the tension.
N&N research is further experienced as 'very expensive', 'dynamic', 'complex' and yet 'ill-defined' by postgraduate researchers. The researchers carry an impression that physical and chemical properties at nanoscale are very different, difficult to predict and explain. The researchers' background knowledge of the subject and awareness is mainly implemented in designing the experiments. The researchers appear to put most effort into the experimentation work and think that complex phenomenon at nanoscale can only be understood through the experimental observations. The postgraduate researchers also feel responsible due to large amount of financial investment in the research and tend to be more disciplined and organised in their research. The fast pace of the developments in the area and competitive environment have built a lot of mental pressure on the researchers but at the same time tune them to be more alert and up to date to survive in the competition.

> *Although it is so expensive and complex venture, we know that there are few groups which have capabilities that we have in our lab and it makes WWWW so much competitive…I have worked for HHHH for last few months and just before drafting ….. I saw that PPPP have recently published it…I have to work fast…I am still undergoing through….. (PhD researcher F)*

CONCLUSION

Our analysis of the pilot interviews suggested that interview questions and structure were successful in gathering researchers' experiences of N&N research. Although it would be too early to come to any conclusions from the pilot interviews, it is evident that the postgraduate researchers struggle in some situations such as working in collaborative research, discussing their research work in conferences and planning research work in laboratory. The future interviews can be designed to collect deeper experiences which will inform the complexities in these areas. But off course it will remain open ended encouraging the participants' to describe all possible experiences of researching in this area. In conclusion, the pilot interviews served the purpose of exploring the research process and have helped us to decide how to proceed with the proposed research. We will continue to develop a greater understanding of N&N area from researchers' perspectives in future interviews.

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